

## DESIGN APPLICATION AND DEVELOPMENT OF SPACECRAFT IN LEO UTILIZING LDEF RESULTS

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### SUMMARY

In general, the results from the Long Duration Exposure Facility (LDEF) have provided much useful information on material sensitivity in the low-Earth orbit (LEO) environment. This is particularly true for selected materials such as thermal control coatings, composites, polymers, fasteners and solar cells. However, LDEF material sensitivity data for other materials like glasses, glass coatings, lubricants, adhesives and seal materials were limited. Some of this important LDEF material sensitivity data has not yet been addressed in detail at the LDEF meetings.

The type of material information needed in the design and development of an new spacecraft in LEO depends to a large extent on program phase. In early program phases it is only necessary to have material sensitivity data to determine what materials may or may not work. Later program phases require details on the material strength, optical properties, and/or other long term survivability requirements for materials in LEO.

Unfortunately, documentation of exposure results for many materials sensitivity experiments that flew on LDEF has not yet been summarized in a convenient form for use by multiple users. Documentation of this data in a form convenient for scientists, engineers as well as technicians remains a significant area of concern for the Aerospace industry.

Many of the material experiments that flew on LDEF were only designed to measure material sensitivity for one year in an LEO environment. However, some materials expected to survive one year simply did not survive the 5.8 years that LDEF eventually remained in orbit. Therefore the survivability of several materials in an LEO environment was determined by default. Most of the LDEF materials experiments were not designed to establish long term material survivability data. This long term material survivability data is particularly useful in later program phases of Spacecraft development. The lack of more controlled materials experiments to determine long term material survivability was one of the major limitation of many LDEF experiments. The identified need for this critical information on the long term material survivability offers a challenge to possible future LDEF type experiments.

## INTRODUCTION

The LDEF was deployed into LEO in April of 1984 and retrieved by the space shuttle in January of 1990. Some 10,000 plus materials and samples were on board (ref. 1). It also contained 57 experiments (ref. 1) for further defining the space environments and effect on materials. Two LDEF conferences in '91 and two in '92 have given principal investigators several opportunities to present their LDEF results and findings. Several summaries of LDEF materials have appeared in the literature (refs. 2,3) that attempted to combine the results from several principal investigators.

The design and development of new spacecraft is expected to be strongly dependent on the utilization of LDEF results. The successful application of LDEF materials results to new spacecraft will at some point require that they be in a form that can meet several needs including:

- Multiple users must be considered including; scientists, engineers, technicians and operators.
- Different components of LDEF results will need to be addressed when considering different mission types including; short duration in LEO, long duration in LEO, intermediate orbital altitude, GEO applications, and translunar and planetary space applications.
- Material life analysis detail needed from LDEF results will depend on the program phase i.e., concept, design, verification.
- LDEF data will need to be accessible and user friendly

In general, the results from LDEF have provided much useful information on material sensitivity in the LEO environment. This is particularly true for selected materials such as thermal control coatings, composites, polymers, fasteners, solar cells, etc. However, LDEF material sensitivity data for other materials like glasses, glass coatings, lubricants, adhesives and seal materials was limited. Many of the material experiments that flew on LDEF were only designed to measure material sensitivity for one year in an LEO environment. However, some materials expected to survive one year simply did not survive the 5.8 years that LDEF eventually remained in orbit. Therefore the survivability of several materials in an LEO environment was determined by default. However, most of the LDEF materials experiments were not designed to establish long term material survivability data.

Unfortunately, documentation of exposure results for many materials sensitivity experiments that flew on LDEF has not yet been summarized in a convenient form for use by multiple users. LDEF results will be used by a broad spectrum of users within the aerospace companies, academic institutions and our society in general. The completion of the documentation of LDEF materials results is critical to insure maximum utility to the many people expected to use this information.

## LDEF DOCUMENTATION

A comprehensive data base for LDEF experiments and LDEF materials that would be most useful to multiple users is described in Figure 1. Documentation in this form would allow several ways to cross reference LDEF results to survey information for a potential material application. If the desired information was not available, then all LDEF experiments with the material of interest

could be identified along with their LDEF location. Information on the principal investigators for these experiments would also identify valuable contacts that could potentially provide additional material data.

Unfortunately, it has been found that the documentation of LDEF results is significantly incomplete. In discussions with various coordinators involved in the documentation of LDEF results at NASA Langley Research Center and elsewhere, the estimated status of incomplete LDEF results has been approximated by the summary in Table 1. It is clear that the reporting of materials results by principal investigators is significantly incomplete. It is also apparent that the documentation of LDEF materials results has not resulted in the kind of data base that would be useful in the design and development of new spacecraft.

## LDEF RESULTS REQUIRED AT SELECTED SPACECRAFT PROGRAM PHASES

The three principal program phases in the development of a new spacecraft are shown in Figure 2 along with the typical time allotted for these phases. The type of material information needed in the design and development of a new spacecraft in LEO depends to a large extent on program phase. In early program phases it is only necessary to have material sensitivity data to determine what materials may or may not work. Some typical evaluations that would be considered for the concept phase of a space craft program are shown in Table 2. Also included in this table are the materials requirements for the Concept phase. As indicated only materials screening results are required for the concept phase since many materials are being considered.

Long term material survivability data is particularly useful in later program phases of Spacecraft development. For both the Design and Verification phases of a spacecraft program as described in Tables 3 and 4 additional information on material life is required. Later program phases require details on the material strength, optical properties, and/or other long term survivability considerations for materials in LEO. The most detailed material life considerations are usually addressed in the Verification phase when maintenance and replacement times are needed for specific material applications.

The lack of more sequenced time phased measurements on LDEF to estimate long term material survivability was one of the major limitations of most material experiments on LDEF.

## EVALUATION OF MATERIAL LIFE ON LDEF

Several approaches were used to evaluate material life for the experiments on LDEF. These approaches are summarized in Table 5. The first approach is the pass/fail approach. An example of this approach was the single aluminized Kapton layer that was used as the outer layer of the McDonnell Douglas MLI experiment A0076 (ref. 4). Since the uncoated side of this film was exposed to atomic oxygen in a near ram direction, it was degraded to the point of complete decomposition during the 5.8 years LDEF was in orbit. For this example, it is known that the single aluminized Kapton failed on orbit but it is not known how long it survived before failure. There were no intermediate measurements.

The second type of life failure analysis in Table 5 can be illustrated using the evaluation of the chromic acid anodized tray clamps. For this case, the optical properties of these clamps have been evaluated for all the trays on LDEF. The absorptance and emittance were plotted by Plagemann (ref. 5) as a function of the tray position. Plagemann (ref. 5) also plotted the absorptance and emittance as a function of the solar radiation and atomic oxygen fluence found for chromic acid anodized clamps at each tray position. He found that there was a correlation for the absorptance measurements with atomic oxygen fluence but not with solar radiation fluence. This result turned out to be related to the accumulation of contamination. This result could have also been related to the accumulation of either atomic oxygen or solar radiation to estimate life of a material in space. Here the higher fluence would be considered the longer time in space. However, there are some complications with this type of life analysis. To better understand these complications, some significant details of these fluence calculations will be described.

Bourassa et al. (ref. 6) developed computer programs that were used to predict the total fluence of atomic oxygen and solar radiation received by each tray on LDEF. The LDEF satellite was a 12 sided polygon structure with two additional sides; one facing Earth (Nadir) and the other facing space (Zenith) respectively. If the LDEF satellite could be simplified as a six sided box structure with one side always facing the ram direction, then the total 5.8 year fluences for atomic oxygen and solar radiation calculated by Bourassa et al. (ref. 6) can be described as a percentage of the largest fluence as summarized in Table 6. These results show that the largest solar radiation fluence is in the zenith direction and the maximum atomic oxygen fluence is in the ram direction. By contrast the proton radiation fluence established from measurements on LDEF itself have determined that the maximum fluence occurs in the aft direction (refs. 7,8). Electron radiation appears to be more uniform in all directions (ref. 7). It is apparent from the calculations summarized in Table 6 that the space environment for LDEF or any spacecraft in LEO will not be the same in all directions. The space environment will also not be proportional from one position to another since each component of the LEO environment has a different direction for its maximum fluence. As a result, life analyses determined from different locations on LDEF cannot be used directly to extrapolate to an estimated material life. However, such a material life analysis would be possible if only one component of the LEO environment was important and all other components were negligible. An even better life analysis approach would involve the development of some technique that weights the importance of the different components of the LEO environment as one evaluates materials from different locations on LDEF.

The third approach to evaluate material life from LDEF results indicated in Table 5 involves the evaluation of material measurement made at periodic but specified times at the same location on LDEF. Wilkes et al. (ref. 9) had such a carousel on LDEF as indicated in Figure 3. A schematic of this carousel shown in Figure 4 describes the way samples were rotated periodically from the exposed condition to a position where optical measurements for the samples could be made. Periodic time measurements made for the material S13B/LO are shown in Figures 5. In this instance, Wilkes et al. (ref. 9) were able to estimate a projected life for this material using the log-log plot of the data in Figure 5 as shown in Figure 6. While the approach of Wilkes et al. to estimate material life it is not recommended for all material applications these results do illustrate one potentially successful approach.

The fourth and last approach to evaluate material life from LDEF results indicated in Table 5 involves a modification of the approach used by Wilkes et al. For this case Meshishnek et al. (ref. 9) developed a tray, shown in Figure 7, that provided different sample exposure times at the same

location on LDEF but without the capability of making sample measurements on orbit. For this case, the samples had to be returned to earth to make the measurements necessary to estimate material life.

It is apparent that some approaches to estimate material life from LDEF results will be more successful than others. The identified need for information on the long term material survivability offers a challenge to possible future LDEF type experiments to find new and improved approaches to estimate material life.

### WHAT'S NEXT?

Based on the available results from LDEF, it would appear that improved methods to obtain environmental exposure data for use in extrapolating material life are needed. Future flight experiments similar to LDEF that might be pursued in the near future should also extend the LDEF knowledge base in such areas as:

- Additional data on seal materials, glasses, glass coatings, lubricants and adhesives exposed to the space environment are needed
- New materials with expectations of improved performance and durability need to be tested.
- Polar and elliptical orbit data with high particulate radiation would prove useful.
- Effects of active versus passive solar cells should be evaluated
- Improved understanding of synergistic environmental phenomena (UV, atomic oxygen, etc.) on materials degradation needs to be addressed.

In addition to the generation of new data for samples exposed to the LEO environment, it is also important to continue further development of effective ground based simulations to correlate with space based experiments. Good ground based simulation techniques and procedures could help minimize material life evaluation requirements.

### CONCLUDING REMARKS

Well documented LDEF results are very much needed by those engineers associated with spacecraft "Design." Where possible the LDEF data should be organized at different levels of detail consistent with the information required at different phases of a spacecraft program. It is also expected that LDEF results will be used by a broad spectrum of users within the aerospace companies, academic institutions and our society in general. It is very important that LDEF information be available and easily obtainable by all that might want access to it. In particular, this information needs to be provided in a user friendly data base. Unfortunately, it is also apparent the much work still needs to be done to obtain, analyze, and document basic information from unreported LDEF experimental results. Where possible a maximum effort should be made to estimate projected life from LDEF materials data. The completion of a comprehensive LDEF materials data base is critical to insure maximum utility to the many people expected to use this information.

Any new LDEF type materials experiments will need to build on the experience obtained from the current LDEF results. In particular, new and novel ways to predict the long term survivability of materials exposed to the LEO environment are needed. Improved ground based verification techniques are also needed to predict and correlate with LEO materials degradation.

## REFERENCES

1. "69 Months in Space: A History of the First LDEF (Long Duration Exposure Facility)." NASA NMP 149, Langley Research Center.
2. Dursch, H.W., Spear, W.S., Miller, E.A., Bohnhoff-Hlavacek, G.L., and Edelman, J.: "Analysis of Systems Hardware Flown on LDEF—Results of the Systems Special Investigation Group." Boeing Defense and Space Group, Contract NAS1-19247, NASA Contractor Report 189628, April 1992.
3. Stein, B.: "LDEF Materials: An Overview of the Interim Findings." LDEF Materials Workshop '91, NASA Conference Publication 3162, Proceedings of a Workshop held at NASA Langley Research Center, pp. 1–56, November 19–22, 1991.
4. Smith, C.A., Hasegawa, M.M., and Jones, C.A.: "Space Station WP-2 Application of LDEF MLI Results." LDEF Materials Results for Spacecraft Applications Conference, Huntsville, Alabama, October 27–29, 1992.
5. Plagemann, W.L.: "Space Environmental Effects on the Integrity of Chromic Acid Anodized Coatings." LDEF—69 Months in Space, First Post-Retrieval Symposium, NASA Conference Publication 3134, Proceedings of a Symposium Held in Kissimmee, Florida, pp. 1023–1040, June 2–8, 1991.
6. Bourassa, R., Gillis, J.R., and Rousslang, K.W.: "Atomic Oxygen and Ultraviolet Radiation Mission Total Exposure for LDEF Experiments." LDEF—69 Months in Space, First Post-Retrieval Symposium, Arlene S. Lavine, ed., NASA Conference Publication 3134, Part 2, June 2–8, 1991.
7. Armstrong, T.W., Colborn, B.L., and Watts, J.W.: "Ionizing Radiation Calculations and Comparisons With LDEF Data." LDEF—69 Months in Space, First Post-Retrieval Symposium, Arlene S. Lavine, ed., NASA Conference Publication 3134, pp. 347–357, June 2–8, 1991.
8. Harmon, A., (Based on Sodium 22 Measurements), Personal Communication, October 19, 1992.
9. Wilkes, D., Brown, M.J., Hummer, L.L., and Zwiener, J.M.: "Initial Materials Evaluation of the Thermal Control Surfaces Experiment (S0069)." LDEF—69 Months in Space, First Post-Retrieval Symposium, Arlene S. Lavine, ed., NASA Conference Publication 3134, pp. 899–917, June 2–8, 1991.
10. Meshishnek, J.J., Gyetvay, S.R., and Jagers, C.H.: "Long Duration Exposure Facility Experiment M0003 Deintegration/Findings and Impacts." LDEF—69 Months in Space, First Post-Retrieval Symposium, Arlene S. Lavine, ed., NASA Conference Publication 3134, pp. 1073–1107, June 2–8, 1991.

Table 1. Status summary of materials data base for LDEF.

	Percent Materials Identified	Percent Materials Results reported	Percent Materials Documented in Data Base
Adhesives	90	<50	0
Seals	90	<50	0
Solar Cells	100	<<50	25
Lubricants	90	<50	0
Optical Fibers	100	<50	25
Optical Glasses	75	<50	25
Optical Coatings	75	<50	25
Batteries	100	<50	0
Composites	95	<50	0
Plastics	90	<50	0
Velcro	90	<<50	0
Fasteners	90	<<50	10
Thermal control Coatings	90	<<50	25
Paints	90	<<50	20
Multilayer Insulation	90	<<50	0
Thermal Blankets	90	<<50	25

Table 2. Concept phase mission profile evaluation and materials requirements.

### **Mission Profile**

- **Application Altitude (i.e. LEO, GEO, etc.)**
- **Environment (Atomic Oxygen, UV Radiation, Electron/Proton Radiation, etc.)**
- **Reboost Schedule**
- **Hardware Function**

### **Materials Screening**

- **Operational Scenario for each Material**
- **Potential Materials for Application**
- **Literature Review of Available Materials Data Described by Mission Profile**
  - **Materials Susceptibility Data**
  - **Materials Projected Life Data**

Table 3. Design phase materials requirements.

**Hardware Analysis and Testing**

- **Stress/Strain Evaluations**
  - **Environmental Impact Analysis**
    - \* **Model Spacecraft Microenvironments**
- **Materials Protection Guidelines**
  - **Optical Properties Changes to Exterior and Interior Coatings**
  - **Bumpers, Shields, Thermal Isolators Design Guidelines**
  - **Single Event Upset Guidelines**
  - **End of Life Performance of Solar Cells and Batteries**

**Materials Selection from Analysis and Testing**

- **Correlate Space Test Results to New Spacecraft Design**
- **Evaluate Materials as Described by Operational Scenarios**
  - **Materials Environmental Susceptibility Data**
  - **Materials Projected Life Data**

Table 4. Verification phase materials requirements.

**Hardware Function for Life of Spacecraft**

- **Materials Replacement Schedule**
  - **Materials Projected Life Evaluation**
    - \* **Accelerated Life Testing**
    - \* **Combined Environmental Testing**
    - \* **Validation of Laboratory Environmental Testing to on Orbit Performance**



Table 5. Approaches to evaluation of expected life for materials on LDEF.

- (1) Expected Life < 5.8 years ----- material failed on orbit
  - Single aluminized Kapton film removal on leading edge experiment A0076
- (2) Identical material experiments at various locations around LDEF allowed utilization of different LDEF environments to extrapolate life
  - Chromic acid anodized plates on all LDEF experiment trays
- (3) Material experiment periodic measurements on orbit at one location on LDEF allowed life extrapolation
  - Rotating sample carousel with periodic optical measurements on experiment S0069
- (4) Material experiment provided moveable canisters to provide several exposure times to identical samples on orbit at one LDEF location to extrapolate life
  - Aerospace Corporation sample canisters that opened in three stages on experiment M0003 (trays D4 and D8)

Table 6. Calculated levels of environmental components for sides of orbiting box structure.

Orbiting Box Side	Percent Total LDEF Fluence			
	Solar Radiation*	Atomic Oxygen*	Electron Radiation**	Proton Radiation**
Zenith Side	100.	4.4	100.	56.
Ram Side	77.	100.0	100.	61.
Aft Side	77.	$5.7 \times 10^{-13}$	100.	100.
Starboard Side	46.	4.4	100.	90.
Port Side	46.	4.4	100.	67.
Nadir Side	31.	4.4	100.	56.

#### References

- \* Roger Bourassa, J.R. Gillis, and K.W. Rousslang, "Atomic Oxygen and Ultraviolet Radiation Mission Total Exposure for LDEF Experiments", LDEF -69 Months in Space, First Post -Retrieval Symposium, Arlene S. Lavine -Editor, NASA Conference Publication 3134, Part 2, June 2-8, 1991
- \*\* T.W. Armstrong, B.L. Colborn, & J.W. Watts, " Ionizing Radiation Calculations and Comparisons with LDEF Data", NASA Conf. Publication 3134, LDEF 69 Months in Space, First Retrieval Symposium, June 2-8, 1991, Page 347-357----- And personal communication with Allen Harmon (10/19/92) and based on Sodium 22 measurements

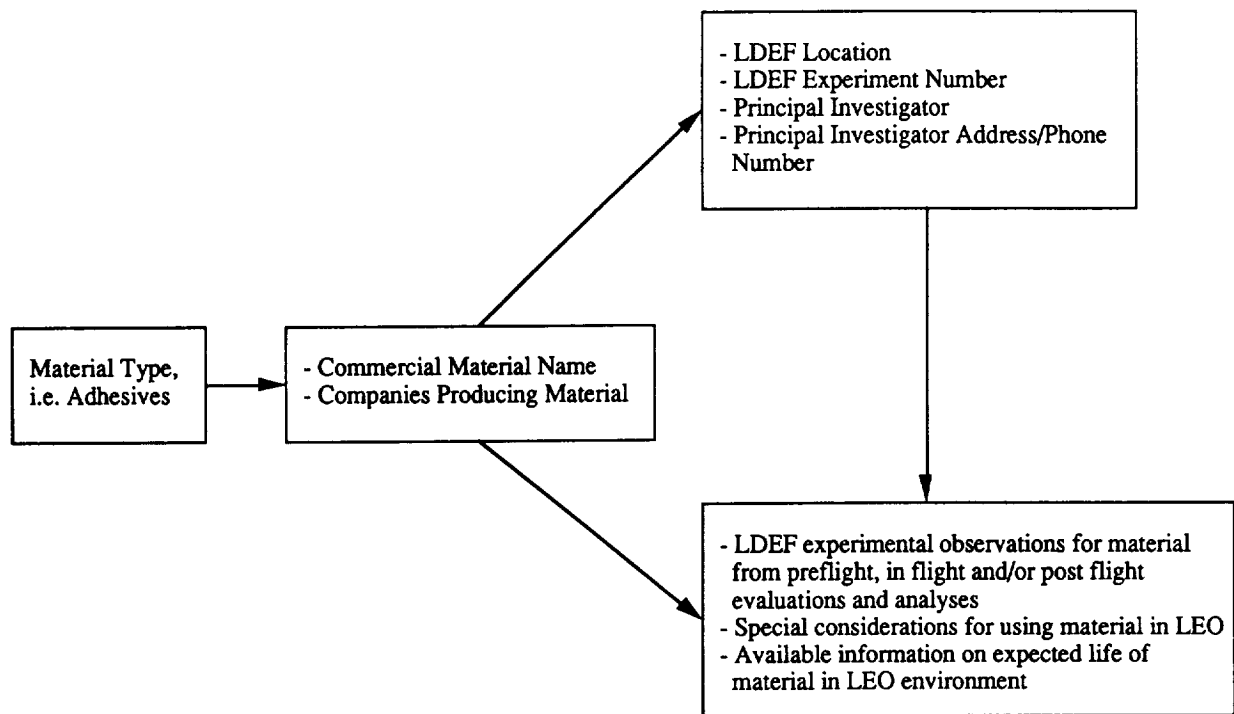


Figure 1. Preferred data base for LDEF experiments and materials.

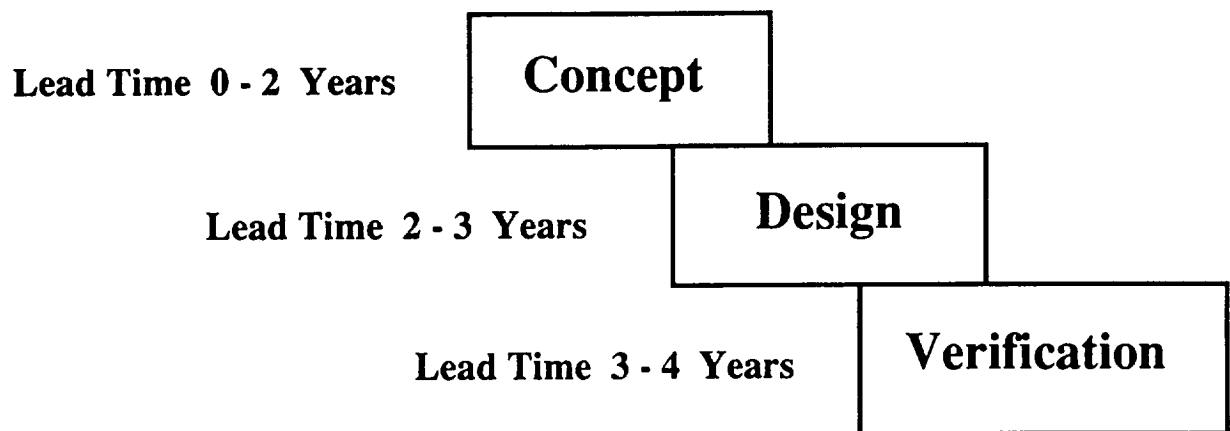


Figure 2. Spacecraft program phases.

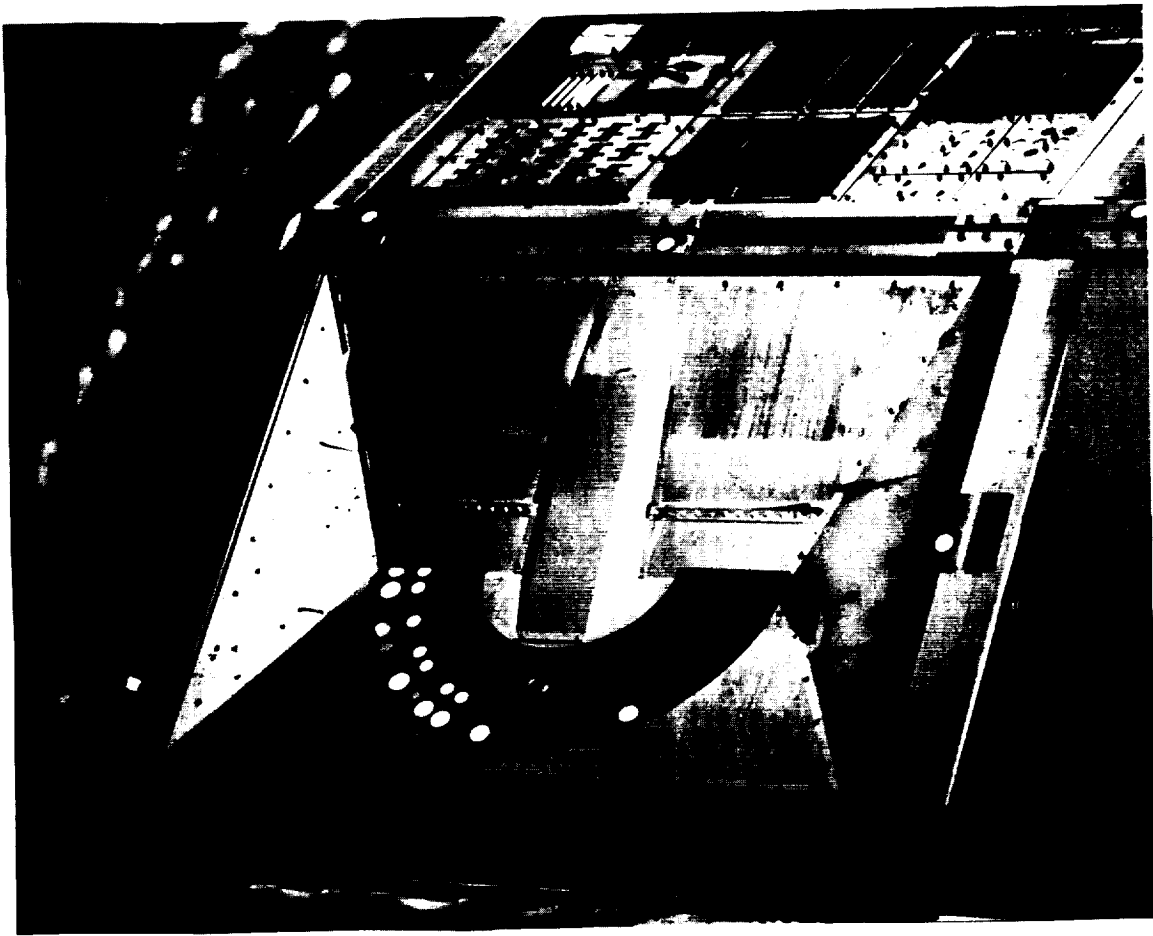


Figure 3. Thermal control surfaces experiment (TSCE) on LDEF.  
(Photo courtesy of AZ Tech and NASA Marshall.)

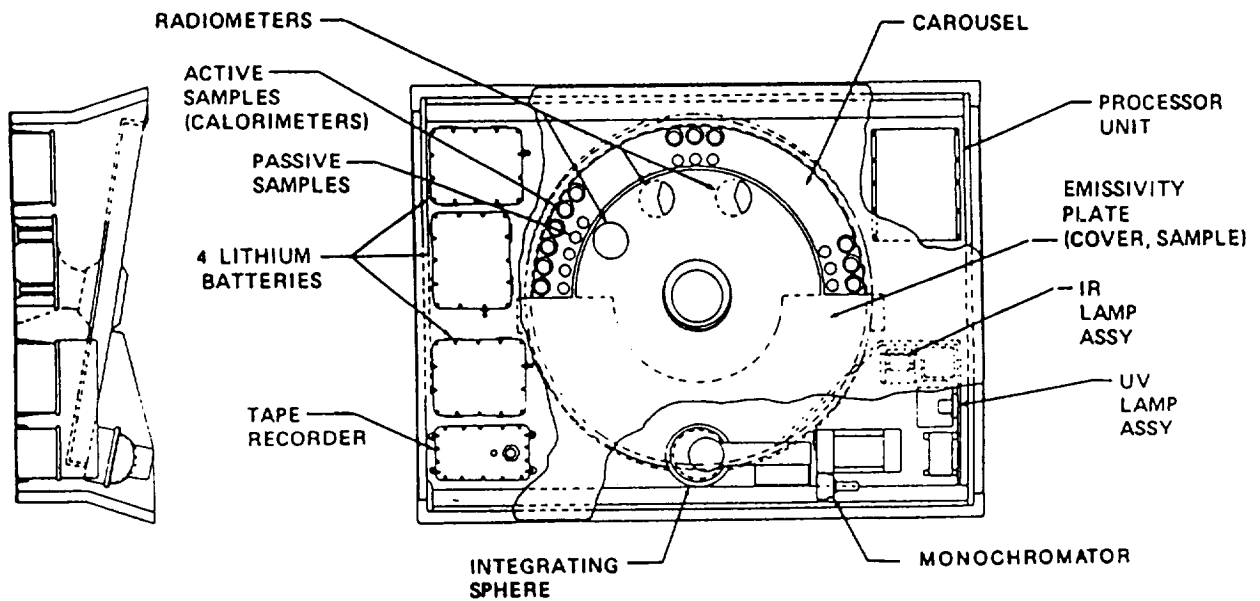


Figure 4. Schematic of TCSE on LDEF.  
(Schematic courtesy of AZ Tech and NASA Marshall.)

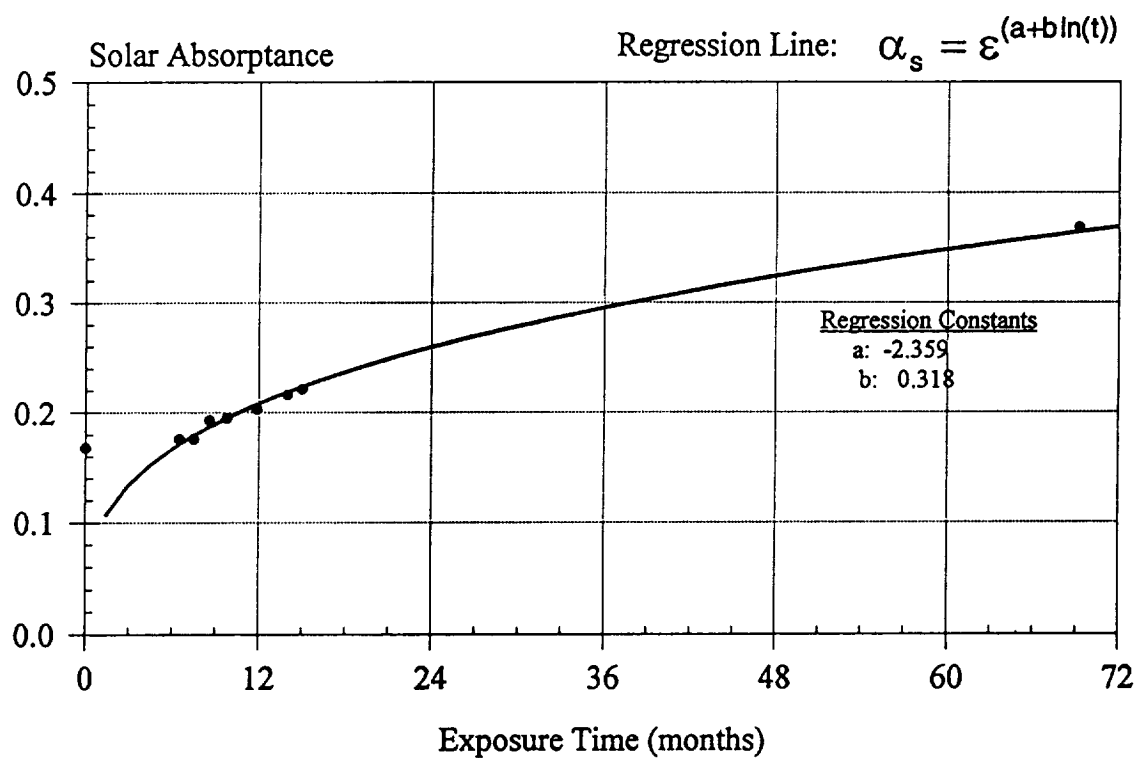


Figure 5. Power regression analysis of S13G/LO LDEF results.  
(Courtesy of AZ Tech and NASA Marshall.)

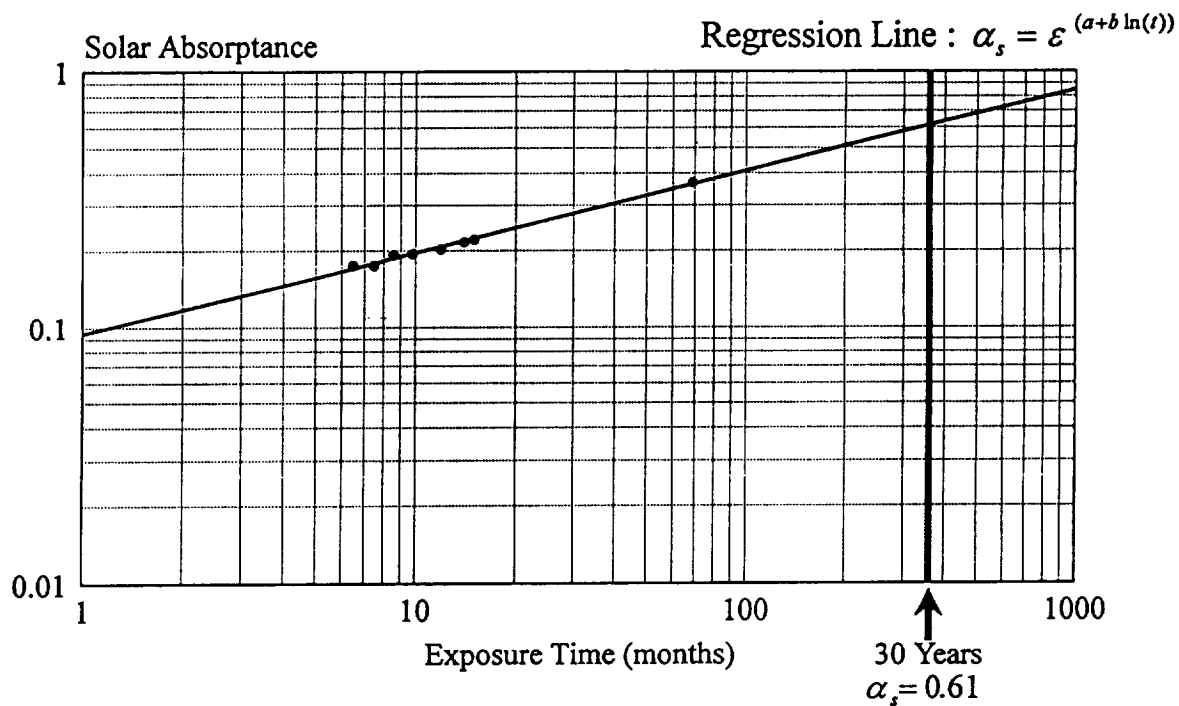


Figure 6. Log/log plot of S13G/LO LDEF data.  
(Courtesy of AZ Tech and NASA Marshall.)

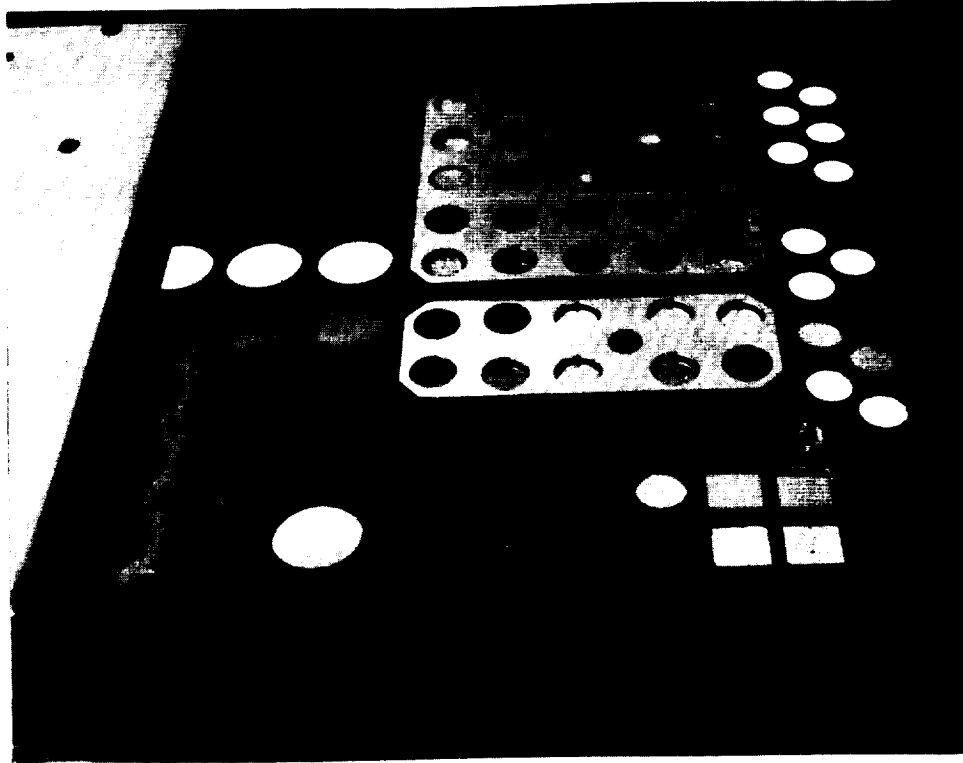


Figure 7. Aerospace Corporation LDEF canister. Identical samples exposed 9, 19, and 40 weeks with adjustable tray. (Courtesy of Aerospace Corporation.)

